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Author Names & Affiliations

- Junjie Zhu - Illinois Institute of Technology
- Paul Anderson - Illinois Institute of Technology

Contact Email Address (for NSF use only)

(Hidden)

Research Domain, discipline, and sub-discipline

Environmental Engineering

Title of Submission

Soft-sensor application for enhancing cost-effective operations at water reclamation plant

Abstract (maximum ~200 words).

Older water reclamation plants (WRPs) typically operate with excess aeration to manage various perturbations and meet their effluent permit requirements. Aeration accounted for about 60% of energy costs at WRPs; Our studies suggested that aeration-associated energy can be substantially reduced (up to 50%) at the MWRDGC Calumet WRP even during challenging influent scenarios, effluent permit requirements can be well satisfied, and process resilience can be maintained. To achieve this more cost-effective operation state, a major challenge is to acquire appropriate data on influent wastewater and process characteristics. Much of information is difficult or very costly to measure by hard sensors. To address this issue, we have been investigating an alternative way, soft sensors, to predict needed information based on historical data and easily-acquirable information. Current challenges of soft-sensor application include limitation of temporal resolution of the data and prediction of BOD data, which need to be addressed before deployment.

Question 1 Research Challenge(s) (maximum ~1200 words): Describe current or emerging science or engineering research challenge(s), providing context in terms of recent research activities and standing questions in the field.

Older water reclamation plants (WRPs) were designed when control techniques were relatively primitive and energy consumption was not a major concern. Therefore, although process operations at these plants can satisfy effluent permit requirements, they typically operate with excess aeration. Upgrade of existing control techniques to a more advanced and intelligent approach based on cyber-physical system (CPS), will help to minimize excess energy use and lower greenhouse gas emissions, while maintaining the process resilience to successfully manage influent perturbations. Aeration accounted for about 60% of energy costs at WRPs (Duchene et al., 2001; Ingildsen, 2002). Our studies (Zhu, 2015; Zhu et al., 2015; Zhu and Anderson, 2017) suggested that aeration-associated energy can be substantially reduced (up to 50%) at the Metropolitan Water Reclamation District of Greater Chicago (MWRDGC) Calumet WRP even during challenging

influent scenarios, effluent permit requirements can be well satisfied, and process resilience can be maintained. To achieve this more cost-effective operation state, a major challenge is to acquire appropriate data on influent wastewater and process characteristics. There are several challenges associated with the hard sensors that are typically used to collect this kind of information.
• Hard sensors, such as D.O. probes commonly used to monitor the oxygen level in aeration tank; they are seldom used to measure influent conditions, so the information they acquire may not be useful for an effective process controlling because of time delay.
• Hard sensor deployment in extreme environments can be costly. In contrast with relatively clean-water applications, such as river and lake, sensors in wastewater are faced with fouling problems, and frequent cleaning and replacement can significantly increase the costs.
• Some important constituents are very difficult or costly to measure. For example, five-day biochemical oxygen demand (BOD5), usually requires five days to measure due to slow biological reactions. As a result, conventional WRPs do not have real-time BOD5 data.

Question 2 Cyberinfrastructure Needed to Address the Research Challenge(s) (maximum ~1200 words): Describe any limitations or absence of existing cyberinfrastructure, and/or specific technical advancements in cyberinfrastructure (e.g. advanced computing, data infrastructure, software infrastructure, applications, networking, cybersecurity), that must be addressed to accomplish the identified research challenge(s).

To address these issues, we have been investigating soft sensors, a mathematical or statistical approach to predict needed information based on historical data and easily-acquirable real-time information. Advantages of soft-sensor approach include low cost, fast response times, and the ability to work in parallel or integrated with hard sensors to enhance the reliability of process control (Fortuna et al., 2007). Soft sensors also have other advantages that conventional hard sensors do not have, including the ability to predict future information, the ability to detect error or improper information, and self-learning. Soft sensors are commonly data-driven; data quantity and data quality are critical to providing good predictions. Missing data and outliers are common problems when dealing with large datasets that have many variables. Typical approaches for managing missing data can result in the loss of information or require intensive computations; we developed a simple but effective approach, iterated stepwise multiple linear regression (ISMLR), to retain appropriate data and provide a primary prediction (Zhu and Anderson, 2016). ISMLR based on default values can provide very good predictions on the current day's ammonia concentration and the next day's flowrate. However, two major limitations are required to address before soft sensors applications:
• Temporal resolution of the data. Current datasets typical include daily data, because MWRDGC is required to report the data to U.S. EPA. Although daily data are useful for preliminary investigations, they do not meet the need of a "real-time" prediction. Data that provide at least hourly resolution can be used to study transient conditions. Short-term, on-site data collection may be feasible, but that approach could also require intensive work and high costs because much of the information can't be measured by hard sensors. Long-term data collection, however, is necessary for real-time control. A compromising solution, which needs to be tested, is to learn the pattern and correlations among different variables based on short-term sampling, and use this prior knowledge, regular daily data, and some easily-acquirable real-time information to provide predictions.
• Prediction of BOD data. A default ISMLR approach did not yield the desired accuracy for BOD predictions, primarily due to lack of recent BOD data. Several approaches that could address this issue are:
o Use an on-line BOD sensor, or predict BOD based on an on-line COD sensor, but this approach could be very expensive.
o Integrate decision-making with soft sensors to slightly overestimate BOD data thereby providing the desired amount of risk management (Zhu et al., 2017).
o More advanced soft sensors.

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Consent Statement